UNIVERSITI PUTRA MALAYSIA

EFFECTS OF ENRICHED BIOCHAR AND *Bacillus subtilis* ON GROWTH, PHYSIO-BIOCHEMICAL PROPERTIES AND FUSARIUM WILT INCIDENCE OF BANANA UNDER WATER STRESS

SITI NORLIZA MOHD DIN

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By

SITI NORLIZA BINTI MOHD DIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirement for the Degree of Master of Science

September 2018

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DEDICATION

This research study is dedicated to all scientists, researcher and lecturer around the world who are struggles to keep the sanctity of our earth's atmosphere preserved. For my great and very helpful supervisor Prof Madya Dr. Siti Zaharah Sakimin, the guidance and support you give throughout my study period is priceless. For my beloved parents, Mohd Din Bin Jusoh (father) and Rokiah binti Dollah (mother), this thesis is dedicated for both of you, the cost of bring me up until this level is incalculable.

Thank you Allah

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May Allah rewards all of you

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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Chairman : Siti Zaharah Sakimin, PhD
Faculty : Agriculture

Banana (*Musa acuminata* cv. Berangan) is one of the most popular fruit and has great potential for commercial development since the current demand had increased drastically. However, in Malaysia, poor soil fertility, limited water availability and disease attack are among common problems in banana industry. In order to find a solution of the problems, a field study was conducted to determine the optimum enriched biochar rate for improvement of soil physicochemical properties, growth and physiological status of banana. In addition to field study, a glasshouse study was conducted to determine the effect of *Bacillus subtilis* inoculation in enriched biochar media and water stress on growth, physiological status and suppression of Fusarium wilt. Four different rates of enriched biochar (0, 1.5, 3.0 and 4.5 t ha^{-1}) were applied once by mixing with Bungor Series soil and put into a polybag with the size of 40 cm × 40 cm. One month old banana plantlets were used. The treatments were carried out for 3 months and arranged in a randomized complete block design with 4 replications. Meanwhile, in the second study, the media were prepared based on optimum rate of enriched biochar from the first study. The treatments consisted of two factors (water stress and *Bacillus subtilis*) arranged by split plot in randomized complete block design with three replications. The media were enriched with 0, 20, 40 and 60 mL *Bacillus subtilis* at the concentration 10^8 CFU mL^{-1} applied by soil drenching as pre-inoculation treatments and plantlets were subjected to 100% well-watered (WW), 75% medium-stressed (MS) and 50% severe-stressed (SS) treatments based on field capacity (FC) level. The plantlets inoculated with *Fusarium oxysporum* race 4 (FOC) one week after *Bacillus subtilis* treatments were applied and the plant were destructively sampled at 45 and 90 days after transplanting (DAT). The results found that soil microbial population, soil physicochemical properties (pH, CEC, total C, N, K, Ca and Mg), growth characteristics (plant height, pseudo-stem diameter, total leaf number and total leaf area), mineral content in leaf tissue (N, P, K, Ca and Mg) and photosynthesis rate increased with the increasing rate of

enriched biochar and 4.5 t ha^{-1} was selected as the best treatment. SS treatment significantly reduced growth parameters and physiological status (photosynthesis, stomatal conductance, transpiration and relative water content) and increased accumulation of proline and malondialdehyde content in plant tissue. Chlorophyll content showed increased by higher rates of *Bacillus subtilis* at both 45 and 90 DAT of destructive period. High concentrations of *Bacillus subtilis* (40 and 60 mL) also were found to reduce disease severity under SS but the value increased under MS and WW condition following the time. This finding suggested that, soil amendment with enriched biochar at 4.5 t ha^{-1} was adequate for optimum growth at nursery level (vegetative stages up to 3 months). Inoculation of the media with higher rates of *Bacillus subtilis* able to improved growth, physiological status and nutritional properties of the banana plants under water stress condition, reduced the deleterious effects of stress and helped plantlets to tolerate drought stress to a higher level as compared to non-inoculated plantlets and increase resistance to Fusarium wilt.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN BIOCHAR DIPERKAYA DAN *Bacillus subtilis* TERHADAP PERTUMBUHAN, SIFAT-SIFAT FISIO-BIOKIMIA DAN KEJADIAN LAYU FUSARIUM POKOK PISANG DI BAWAH KEADAAN TEGASAN AIR

Oleh

SITI NORLIZA BINTI MOHD DIN

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Pengerusi : Siti Zaharah Sakimin, PhD
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Pisang (*Musa acuminata* kultivar Berangan) adalah salah satu buah-buahan yang paling popular dan mempunyai potensi yang tinggi untuk pembangunan komersial kerana permintaan semasa telah meningkat secara drastik. Walau bagaimanapun, di Malaysia, kesuburan tanah, bekalan air yang terhad dan serangan penyakit adalah antara masalah biasa dalam industri pisang. Untuk mencari penyelesaian kepada masalah tersebut, kajian lapangan telah dijalankan untuk menentukan kadar optimum biochar diperkaya untuk penambahbaikan kepada sifat-sifat fizikal kimia tanah, pertumbuhan dan status fisiologi pokok pisang. Tambahan kepada kajian lapangan, satu kajian dalam rumah kaca telah dijalankan bagi menentukan kesan inokulasi *Bacillus subtilis* dalam biochar diperkaya dan tegasan air terhadap pertumbuhan, status fisiologi dan pengurangan kepada penyakit layu fusarium. Empat kadar berbeza biochar diperkaya (0, 1.5, 4.5 dan 3.0 t ha^{-1}) dicampur sekali dengan tanah siri Bungor dan dimasukkan ke dalam polibeg saiz 40 cm × 40 cm. Anak pisang berusia sebulan digunakan. Kajian ini telah dijalankan selama 3 bulan dan disusun mengikut reka bentuk susunan blok rawak dengan 4 replikasi. Sementara itu, dalam kajian kedua, media disediakan berdasarkan kadar optimum biochar diperkaya dari kajian pertama. Rawatan terdiri daripada dua faktor (tegahan air dan *Bacillus subtilis*) diatur dengan reka bentuk split plot dalam susunan blok rawak dengan tiga replikasi. Media telah di inokulasi dengan kadar *Bacillus subtilis* berbeza iaitu 0, 20, 40 dan 60 mL pada kepekatan 10^8 CFU mL^{-1} pada tanah sebagai rawatan pre-inokulasi serta didedahkan dengan tiga aras tegahan air iaitu 100% tiada tegahan (WW), 75% tegahan sederhana (MS) dan 50% tegahan teruk (SS) berdasarkan kapasiti lapangan (FC). Anak pokok diinokulasikan dengan *Fusarium oxysporum* race 4 (FOC) seminggu selepas inokulasi *Bacillus subtilis* dan anak pokok di cabut pada 45 hari dan 90 hari selepas pemindahan. Keputusan mendapati populasi mikrob tanah, sifat fizikal kimia tanah (pH, CEC, jumlah C, N, K, Ca dan Mg), ciri-ciri

pertumbuhan (ketinggian pokok, diameter pseudo-stem, jumlah bilangan daun dan luas daun), kandungan mineral dalam daun (N, P, K, Ca dan Mg) dan fotosintesis meningkat dengan peningkatan kadar biochar diperkaya dan kadar 4.5 t ha^{-1} dipilih sebagai kadar terbaik. Rawatan SS menunjukkan pengurangan yang ketara bagi parameter pertumbuhan, status fisiologi (fotosintesis, konduktan stomata, transpirasi dan kadungan air relatif) dan telah meningkatkan kandungan proline serta malondialdehyde dalam tisu tumbuhan. Kandungan klorofil juga meningkat dengan peningkatan kadar *Bacillus subtilis* pada kedua-dua tempoh anak pokok dicabut iaitu 45 dan 90 hari selepas pemindahan (DAT). Kepekatan yang tinggi *Bacillus subtilis* (40 dan 60 mL) juga telah didapati dapat mengurangkan insiden penyakit di bawah keadaan SS tetapi nilai tersebut meningkat di bawah keadaan MS dan WW mengikut peredaran masa. Kajian ini mendapati tanah campuran dengan biochar diperkaya pada kadar 4.5 t ha^{-1} mencukupi untuk pertumbuhan optimum di peringkat nurseri (tahap vegetatif 1-3 bulan). Inokulasi media dengan *Bacillus subtilis* juga mampu memperbaiki pertumbuhan, status fisiologi dan ciri nutrisi pokok pisang di bawah keadaan tegahan air, mengurangkan kesan bahaya tekanan dan membantu anak pokok bertahan di bawah keadaan kekurangan air ke tahap yang lebih tinggi berbanding pokok yang tidak diinokulasi dan meningkatkan kerintangan pokok terhadap serangan penyakit layu fusarium.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
AA	Auto Analyzer
AAS	Atomic Absorption Spectrometer
ABA	Abscisic Acid
CFU	Colony Forming Unit
CV	Coeffiecient of Variation
cv.	Cultivar
C	Carbon
Ca	Calcium
C:N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
DAT	Day After Transplanting
DF	Degree of Freedom
DOA	Department of Agriculture
EC	Electrical Conductivity
EFB	Empty Fruit Bunch
et al.	And Friends
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistical Database
FC	Field Capacity
FW	Fresh Weight
gs	Stomata Conductance
K	Potassium
Kg/polybag	Kilogram per polybag
LSD	Least Significant Different
Ps	Photosynthesis
PGPR	Plant Growth Promoting Rhizobacteria
R:S	Root to shoot ratio
RCBD	Randomized Complete Block Design
rpm	Rotation Per Minute
RM	Ringgit Malaysia
SAS	Statistical Analysis System
Ts	Transpiration Rate
vs	Versus
v/v	Volume per volume
VPD	Vapour Pressure Deficit
WUE	Water Use Efficiency
WS	Water Stress

CHAPTER 1

INTRODUCTION

Banana which is considered as "queen of tropical fruits" ranked fourth in term of production after oil palm, rubber and paddy. It is also the second most widely cultivated fruit crop which covers 10% of total fruit area (297, 860 ha) and total production of 535, 000 tonnes (Mohamad Roff, 2012). Production value of banana also had increased from RM3.63 billion in 2009 to RM4.57 billion in 2013 (Anonymous, 2014). Currently, major amount of banana production goes to local consumption and only remaining 15% are for export (Kayat et al., 2016). Most cultivated cultivars are Pisang Berangan, Cavendish and Pisang Tanduk which is commonly consumed as sweet dessert and Pisang Tanduk for crisp production. Other famous cultivated cultivar includes Pisang Nangka, Pisang Rastali, Pisang Mas, Pisang Abu and Pisang Awak (Kayat et al., 2016).

Since banana consumption is increasing every year, it has gained attention for the government to increase the cultivation area. The effort has been given by selecting certain area for banana cultivation. For instance, the district of Jeli has been chosen as main area and supplier of banana in Kelantan. The project was also implemented in other state in Malaysia.

Despite of a good government intention to increase banana production, there are some restriction encounters by banana growers to achieve optimum growth and high banana yield in Malaysia. Poor soil fertility, limited water availability and disease attack are among of the major problems reported recently. In Malaysia, 72% areas are covered by ultisol and oxisol. The soils are highly weathered, high accumulation of sesquioxides, prone to leaching of plant nutrients and lacking in organic matter (Anda et al., 2010). Besides that, soil in Malaysia is usually acidic as Malaysia receives high rate of total rain annually with pH between 4.2 to 4.8. Acidic rain water will drain directly into the soil surface and will destroy the mineral and absorb organic matter inside the soil. The acidic soil contains low nutrients properties needed for plant uptake. Acidic soil also prevents growth of the plant because the soil contains high toxicity of aluminium (Al) and manganese (Mn) but deficiency in calcium (Ca), magnesium (Mg) and phosphorus (P) (Haynes and Mokolobate, 2001). Moreover, in some area like Selangor, Kelantan, Perlis, Kedah and Perak, limited water source and growing competition for clean water reduced growth performance of banana. Many crop experienced water stress which negatively affect the plant's production. Drastic climate changes in this few years also become major problem since it can affect whole plant growth performance.

For the past few years also, many areas in Malaysia experienced flood which adversely effected to agriculture sector. The flood generally causes the spreading of the soil and water borne diseases. The most commonly occur and devastated disease in banana is Fusarium wilt and Moko disease. Re-emergence of soil-borne fungus *Fusarium oxysporum* f.sp. *cubense* (Foc) is one of the major

constraints in banana production. The disease inoculum usually disseminated via contaminated soil on wheels and shoes, contaminated tools, runoff, flooding and irrigation water which eventually infected planting material (Ploetz, 2015). Upon infection to the root tissue, first they invade the xylem vessel, caused necrosis on the corm, restricted the water movement in the vascular bundles and eventually resulted in lethal wilting of the infected plant (Yadeta and Thomma, 2013). Early infection during vegetative stage caused plant to die without bearing fruit.

Currently, enrichment of soil fertility using organic amendments and induction of disease tolerance using plant growth promoting rhizobacteria has been proven to improve soil fertility and increase plant tolerance to disease in several crop plants. However, there is little information about the interactive effect of rhizobacteria with biochar and/or compost, particularly under water stress conditions of banana plants. Because of the relatively large area of Ultisols in the tropics, and thus the high potential for banana cultivation, it is important to develop measures to ameliorate the soil acidity and to reduce disease severity for sustainable banana production. Hence in view of the above problems, the current study was conducted with the following objectives:

1. To determine the optimal rate and effectiveness of enriched biochar on the physicochemical properties of media, growth and physiological status of banana at vegetative stage.
2. To determine the effect of *Bacillus subtilis* on growth, physiological status and biochemical accumulation for suppression of Fusarium wilt disease under water stress condition in enriched biochar amended soil.

REFERENCES

Abbas, T., Rizwan, M., Ali, S., Zia-ur-Rehman, M., Qayyum, M.F, Abbas, F., Hannan, F., Rinklebe, J., & Sik Ok, Y. (2017). Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. *Ecotoxicology and Environmental Safety*, 140: 37–47.

Abbasi, M.K, Sharif, S., Kazmi, M., Sultan, T., & Aslam, M. (2011). Isolation of plant growth promoting rhizobacteria from wheat rhizosphere and their effect on improving growth, yield and nutrient uptake of plants. *Plant Biosystem*, 145: 159-168.

Abeer, H., Abd_Allah, E.F., Alqarawi, A.A., & Al-Huqail, A.A. (2015). Impact of plant growth promoting *Bacillus subtilis* on growth and physiological parameters of *Bassia indica* (Indian bassia) grown udder salt stress. *Pakistan Journal of Botany*. 47(5):1735-1741.

Adila, M.D.H. (2016). Effect of Biorichar as planting media and fertilizer application on growth performance and yield of eggplant (*Solanum melongena* L.). Universiti Putra Malaysia. FYP thesis.

Ahemad, M. & Kibret, M. (2014). Mechanisms and applications of plant growth promoting rhizobacteria. *Journal of King Saud University Science*, 26: 1-20.

Akhtar, S.S, Li, G., Anderson, M.N, & Liu, F. (2014). Biochar enhances yield and quality of tomato under reduced irrigation. *Agriculture Water Management*, 138: 37-44.

Allahmoradi, P., Ghobadi, M., Taherabadi, S., & Taherabadi, S. (2011). Physiological aspects of mung bean (*Vigna radiata* L.) in response to drought stress. In: *International conference on food engineering and biotechnology*, pp 272–27.

Altuhaish, A., & Hamim Tjahjoleksono, A. (2014). Biofertilizer effects in combination with different drying system and storage period on growth and production of tomato plant under field conditions. *Emirate Journal of Food and Agriculture*, 26: 716-722.

Amir, H.G, Shamsuddin, Z.H., Halimi, M.S, Ramlan, M.F & Marziah, M. (2002). N2 fixation, plant growth enhancement and root-surface colonization by rhizobacteria in association with oil palm plantlets under in vitro conditions. *Malaysian Journal of Soil Science*, 6:75–82

Anda, M., Shamshuddin, J., Fauziah, C.I. & Syed Omar, S.R. (2010). Increasing the organic matter content of an Oxisol using rice husk compost: changes in the composition and its chemistry. *Soil Science Society of America Journal*, 74:1167-1180.

Anonymous (2008). Malaysia Export Statistics, *Department of Agriculture*.

Anonymous (2008). The Biology of *Musa* L. (Banana). Australian Government.

Anonymous, (2013). Banana cultivation guide. Retrieved from http://www.bananaplanters.com/site/banana-cultivation-guide/

Anonymous, (2014). Statistik Utama Pemasaran FAMA 2014.

Apel, K., & Hirt, H. (2004). Reactive oxygen species: metabolism, oxidative stress, and signal transduction. *Annual Review of Plant Biology*, 55: 373-399.

Armada, E., Portela, G. Roldán, A. & Azcón. R. (2014). Combined use of beneficial soil microorganism and agrowaste residue to cope with plant water limitation under semiarid conditions. *Geoderma*, 232:640-648.

Atkinson, C.J., Policarpo, M., Webster, A.D., & Kingswell, G. (2000). Drought tolerance of clonal Malus determined from measurements of stomatal conductance and leaf water potential. *Tree Physiology*, 20(8):557-563.

Awad Hamad, M., Mahmood, M., Mohd Razi, I., & Mahmud, T.M.M. (2004). The role of cell wall associated peroxidase activity and xylem sap pH in limiting leaf expansion and transpiration of pepper *Capsicum annuum* L. under water deficit. *Journal of Biological Sciences*, 134-141.

Backman, P.A., Wilson, M., & Murphy, J.F. (1997). Bacteria for biological control of plant diseases. In: Rechcigl NA, Rechcigl JE (eds) Environmentally safe approaches to crop disease control. *Lewis, Boca Raton*, pp 95–109.

Bates, L.S., Waldren, R.P. & Teare, I.D. (1973). Rapid determination of free proline for water stress studies. *Plant and Soil*, 39:205-207.

Blake, G.R., & Hartge, K.H. (1986): Bulk Density. Methods of Soil Analysis, Part 1. *Soil Science Society of America*.Madison, USA, 363-376.

Blokhina, O., Virolainen, E., & Fagerstedt, K.V. (2003): Antioxidants, oxidative damage and oxygen deprivation stress: A review. *Annual of Botany*, 91: 179–194.

Blomme, G., Dita, M, Jacobsen, K.M, Vicente, L.P, Molina, A., Ocemati, W., Poussier, S., & Prior, P. (2017). Bacterial diseases of bananas and enset: current state of knowledge and integrated approaches toward sustainable management. *Frontier in Plant Science*.

Boiero, L., Perrig, D., Masciarelli, O., Penna, C., Cassan, F., & Luna, V.(2006).Phytohormone production by three strains of Bradyrhizobium japonicum, and possible physiological and technological implications. *Applied Microbiol Biotechnology*, 74:874 -880.

Boning, C.R. (2006). Florida's best fruiting plants.Pineapples press, Inc, Florida.

Bor, M., Zdemir, F., & Turkan, I. (2003). The effect of salt stress on lipid peroxidation and antioxidants in leaves of sugar beet *Beta vulgaris* L. and wild beet (*Beta maritima* L.). *Plant Science*, 164: 77-84.

Bray, R.H., & Kurtz, L.T. (1945). Determination of total, organic, and available forms of phosphorus is soils. *Soil Science,* 59:39-45.

Bunce J.A. (1996). Does transpiration control stomatal responses to water vapour pressure deficit?. *Plant, Cell and Environment*, 19: 131–135.

Burke, J.M., Longer, D.E., Oosterhuis, D. M., Kawakami, E.M & Loka, D.A. 2014. The effect of biochar source on cotton seedling growth and development and association with conventional fertilizers. *International Journal of Plant & Soil Science,* 3(8): 995-1008.

Cachinero, JM, Hervas, A, Jimenez-Diaz, RM, Tena, M. 2002. Plant defence reactions against Fusarium wilt in chickpea induced by incompatible race 0 of *Fusarium oxysporum f.sp. ciceris* and non-host isolates of *Fusarium oxysporum*, *Plant Pathol*, 51:765-776.

Carter, S., Shackley, S., Sohi, S., Suy, T.B., & Haefele, S. (2013). The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). *Agronomy*, 3(2): 404–418.

Chan, Y.K., McCormick, W.A., & Seifert, KA. (2003). Characterization of an antifungal soil bacterium and its antagonistic activities against Fusarium species. *Canadian Journal Microbiology*, 49: 253–262.

Chapman, H.D. (1965) Cation exchange capacity. In Methods of Soil Analysis (Edited by Black, C. A.) Part 2, pp. 891-901. Number 9 in the series Agronomy: Am. Inst. Agronomy, Madison, Wisconsin.

Chen, C.T., Li, C.C., & Kao, C.H. (1991). Senescence of rice leaves. XXXI. Changes of chlorophyll, proteins and polyamine contents and ethylene production during senescence of a chlorophyll-deficient mutant. *Journal of Plant Growth Regulator*, 10: 201-205.

Chen, T.W, & Wu, W.S. (1999). Biological control of carrot black rot. *Journal Phytopathol*, 147:99–104.

Clifton-Brown, J.C., & Lewandowski, I. (2000). Water use efficiency and biomass partitioning of three different Miscanthus genotypes with limited and unlimited water supply. *Annual Botany*. 86 191–200.

Claoston, N., Samsuri, A. W., Ahmad Husni, M. H., & Mohd Amran, M. S. (2014). Effects of pyrolysis temperature on the physicochemical properties of empty

fruit bunch and rice husk biochars. *Waste Management & Research*, 32(4), 331-339.

Cogger, C.G. (2005). Potential compost benefits for restoration of soils disturbed by urban development. *Compost Science Utilization,* 13:243–251.

Constantine, D., & Rossel, G. (2001). The Musaceae: an annotated list of species of Ensete, Musa and Musella. Retrieved from http://www.users.globalnet.co.uk/~drc/index.htm

Coombs, J., Hind, G., Leegood, R.C., Tieszen, L.L. & Vonshak, A. (1985). Analytical Techniques. In: Techniques in Bioproductivity and photosynthesis 2nd edition. (Eds) J. Coombs, D.O. Hall, S.P. Long and J.M.O. Scurlock. pp. 219-220, Pergamon Press.

Costa, R.C.L, Lobato, A.K.S, Oliveira, Neto, C.F., SantosFilho, B.G., Cruz, F.J.R., & Laughinghouse, IV HD. (2008). Biochemical and physiological behaviorof Vignaunguiculata (L.) Walp.under waterstress during the vegetative phase. *Asian Journal of Plant Science.* 7:44-49.

Cubillos, J.R., Castellanos, D.E., & Argüello, H. (2009). Selección de Microorganismos promotores de crecimiento vegetal (ácido indol acético) a partir de muestras de suelo rizosferico, como primera etapa en el desarrollo de un biofertilizante. *Review Brasilian Agro Ecology,* 4(2).

Dharmakeerthi, R.S., Chandrasir, J.A.S., & Edirimanne, V.U. (2012). Effect of rubber wood biochar on nutrition and growth of nursery plants of Hevea brasiliensis established in an Ultisol, *Springer Plus*, 1:84.

Dix, P.J., Mc Lysaght, V.A. & Plunket, A. (1986). Salt stress resistance mechanisms and in vitro selection procedures In: plant tissue culture and its agricultural applications (Ed.) L.A. Withers and P.G Alderson, pp: 460-469. Butterworths, London

Dodd, I.C., Zinovkina, N.Y., Safronova, V.I., & Belimov, A.A. (2010). Rhizobacterial mediation of plant hormone status. *Annual Applied Biology*, 157: 361–379.

Dong, Y.H. Gusti, A.R. Zhang, Q. Xu, J.L. & Zhang L.H. (2002). Identification of quorum-quenching N-acyl homoserine lactonases from *Bacillus* species. *Applied Environmental Microbiology*, 68:1754-1759.

Drew, C. Za & Soo-Hyung K. (2012). Biochar amendment increases resistance to stem lesions caused by *Phytophtora* spp. in tree seedlings. *Horticulture Science*, 47: 1736-1740.

Elstner, E.F. (1991). Mechanisms of oxygen activation in different compartments of plant cells. In Active Oxygen/Oxidative Stress in Plant Metabolism, E.J.

Pelland and K.L. Steffen, eds (Rockville, MD: *American Society of Plant Physiologists*), pp. 13–25.

Ericsson, T. (1995). Growth and shoot:root ratio of seedlings in relation to nutrient availability. *Plant and Soil*, 168(169): 205-214.

Estrada, G.A., Divan Baldani, V.L., De Oliveira, D.M., Urquiaga, S., & Baldani, JI.(2013). Selection of phosphate-solubilizing diazotrophic Herbaspirillum and *Burkholderia* strains and their effect on rice crop yield and nutrient uptake. *Plant Soil*, 369:115–129.

Fageria, N.K. & Oliveira, J.P. (2014). Nitrogen, phosphorus and potassium interactions in upland rice. *Journal of Plant Nutrition*, 37 (10):1586–600.

Falcao, L.L. Silva-Werneck, J.O. , Vilarinho, B.R., da Silva, J.P., Pomella, A.W.V. & Marcellino, L.H. (2014). Antimicrobial and plant growth-promoting properties of the cacao endophyte *Bacillus subtilis* ALB629. *Journal of Applied Microbiology*, 116: 1584—1592.

FAO. (2017). Banana market review. Retrieved from http://www.fao.org/3/a-i7410e.pdf

FAOSTAT. (2009). The Food and Agriculture Organization Corporate Statistical Database. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. (accessed 8 September 2009)

Farooq, M., Basra, S.M.A., Wahid, A., Cheema, Z.A., Cheema, M.A., & Khaliq, A. (2008). Physiological role of exogenously applied glycinebetaine in improving drought tolerance of fine grain aromatic rice (*Oryza sativa* L.). *Journal Agronomy of Crop Science*, 194: 325–333.

Fghire, R., Anaya, F., Issa, O.A, & Wahbi, S. (2017). Physiological and growth response traits to water deficit as indicators of tolerance criteria between quinoa genotypes, *Journal of Materials and Environmental Sciences*, 8(6): 2084-2093.

Fourie, G., Steenkamp, E.T., Ploetz, R.C., Gordon, T.R., & Viljoen, A. (2011). Current status of the taxonomic position of *Fusarium oxysporum* formae specialis cubense within the *Fusarium oxysporum* complex. *Infect Genetic Evolution*, 11:533–542.

Fravel, D.R. (2005). Commercialization and implementation of biocontrol. *Annual Review.of Phytopathology*. 43: 337-359.

Freitas, M.A., Mederos, F.H., Carvalho, S.P., Guilherme, L.R., Teixeira, W.D., Zhang, H., & Pare, PW. (2015). Augmenting iron accumulation in cassava by the beneficial soil bacterium *Bacillus subtilis* (GBO3). *Frontier Plant Science*, 6:596.

Gadallah, M.A.A. (2000). Effects of indole-3-acetic acid and zinc on the growth, osmotic potential and soluble carbon and nitrogen components of soybean plants growing under water deficit. *Journal of Arid Environments*. 44(4): 451-467.

Gagné-Bourque, F., Bertrand, A., Claessens, A., Aliferis, K.A., & Jabaji, S. (2016). Alleviation of drought stress and metabolic changes in timothy (*Phleum pratense* L.) colonized with *Bacillus subtilis* B26. *Frontier Plant Science*, 7:584.

García-Cristobal, J., García-Villaraco, A. Ramos, B., Gutierrez- Mañero, J. & Lucas. J.A. (2015). Priming of pathogenesis relatedproteins and enzymes related to oxidative stress by plant growth promoting rhizobacteria on rice plants upon abiotic and biotic stress challenge. *Journal of Plant Physiology*, 188:72-79.

García-López A.M. & Delgado, A. (2016). Effect of *Bacillus subtilis* on phosphorus uptake by cucumber as affected by iron oxides and the solubility of the phosphorus source. *Agricultural and Food Science*, 25: 216–224.

Gaskin, J.W., Speir, R.A., Harris, K., Das, K.C,. Lee, R.D. Morris, L.A. & Fisher, D.S. (2010). Effect of Peanut Hull and Pine Chip Biochar on Soil Nutrients, Corn Nutrient Status, and Yield. *Agronomy Journal*, 102: 623-33.

Ghaemi, A., Rahimi, A., & Banihashemi, Z. (2010). Effects of water stress and *Fusarium oxysporum f. sp. Lycoperseci* on growth (leaf area, plant height, shoot dry matter) and shoot nitrogen content of tomatoes under greenhouse conditions. *Iran Agricultural Research*, 28(2):1-2.

Gilman, J.C. (1916). Cabbage yellows and the relation of temperature to its occurrence.*Annual Missouri Botany Garden*, 3:25-81.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biology Fertility Soils*, 35(4): 219–230.

Glick, B.R. (1995). The enhancement of plant growth by free-living bacteria. *Canadian Journal of Microbiology*, 41(2): 109-117.

Grassi, G., Vicinelli, E., Ponti, F., Cantoni, L. & Magnani, F. (2005). Seasonal and interannual variability of photosynthetic capacity in relation leaf nitrogen in a deciduous forest plantation in northern Italy. *Tree Physiology*, 25: 349–360.

Haas, H., & Défago, G. (2005). Biological control of soil-borne pathogens by fluorescent pseudomonas. *National Review Microbiology*. 3: 307-319.

Hafeez, Y., Iqbal, S., Jabeen, K., Shahzad, S., Jahan, S., & Rasul, F. (2017). Effect of biochar application on seed germination and seedling growth of *Glycine max* (L.) merr. under drought stress. *Pakistan Journal of Botany*., 49: 7-13.

Hannaway, D.B.,Bush, L.P., & Leggett, J.E.(1982). Mineral composition of kenhy tall fescue as affected by nutrient solution concentration of Mg and K. *Journal Plant Nutrition,* 5:137-151.

Hasegawa, S., M. Thangaraj and J.C. O' Toole. (2000). Root behavior: field and laboratory studies for rice and nonrice crops. International workshop on physical aspects of soil management. In: rice based crooping system. IRRI, Los Banos, Philippines.

Hashem, A., Abd_Allah, E.F,. Alqarawi , A.A, Radhakrishnan, R. & Kumar, A. (2017). Plant defense approach of Bacillus subtilis (BERA 71) against *Macrophomina phaseolina* (Tassi) Goid in mung bean, *Journal of Plant Interactions*, 12:1, 390-401.

Haynes, R. J., & Mokolobate, M. S. (2001). Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutrient Cycling in Agroecosystems*, 59(1), 47-63.

Heath, RL. & Packer, L. (1968). Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Archives Biochemistry Biophysics*, 125: 180-198.

Hernandez, M. J., Montes, F., Ruiz, F., Lopez, G., & Pita, P. (2016). The effect of vapour pressure deficit on stomatal conductance, sap pH and leaf-specific hydraulic conductance in *Eucalyptus globulus* clones grown under two watering regimes. *Annals of Botany*, 117(6), 1063–1071.

Heslop-Harisson, J.S, & Schawarzacher, T. (2007). Domestication, genomics and the future of banana. *Annals of Botany*, 100: 1073-1084.

Hoffmann, H. P. & D.W. Turner. (1993). Soil water deficits reduce the elongation rate of emerging banana leaves but the night/ day elongation ratio remains unchanged. *Scientia Horticulture*. 54, 1-12.

Humbert, J.G. (1918). Tomato diseases in Ohio. Ohio Agriculture Experiment Sta. Bulletin. 32.

Hyam, R., & Pankhurst, R. (1995). Plants and their names: a concise dictionary. *Oxford University Press*, Oxford.

Ilgin, M., & Caglar, S. (2009). Comparison of leaf stomatal features in some local and foreign apricot (*Prunus armeniaca* L.) genotypes. *African Journal of Biotechnology*. 8: 1074-1077.

Ismail, H., Shamshuddin, J. & Syed Omar, S.R. (1993). Alleviation of soil acidity in a Malaysian Ultisol and Oxisol for corn growth. *Plant Soil.* 151: 55-65.

Jackson, S.G. (1993). Rapid screening test for enterotoxin-producing *Bacillus cereus*. *Journal of Clinical Microbiology*, 31: 972-974.

Jaleel, C.A., R. Gopi & R. Panneerselvam. (2008). Growth and photosynthetic pigments responses of two varieties of *Catharanthus roseus* to triadimefon treatment. *Comptes Rendus Biologies*., 331: 272–277.

Jian, S.H., & Wang C.S. (2013). Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena*, 110: 225-233.

Jiang, L.L, Han, G.M, Lan, Y., Li, S.N, Gao, J.P., Yang, X., Meng, J., & Chen, W.F. (2017). Corn cob biochar increases soil culturable bacterial abundance without enhancing their capacities in utilizing carbon sources in Biolog Eco-plates. *Journal of Integrative Agriculture*, 16(3): 713–724.

Kallarackal, J., Milburn, J.A. & Baker, D.A. (1990). Water relations of the banana. III effects of controlled water stress on water potential, transpiration, photosynthesis and leaf growth. *Australian Journal of Plant Physiology*, 17: 79-90.

Kamel, A., & Loser, D.M., (1995). Contribution of carbohydrates and other solutes to osmotic adjustment in wheat leaves under water stress. *Journal Plant Physiology*. 145: 363–366.

Kammann, C.I., Schmidt, H.P., Messerschmidt, N., Linsel, S., Steffens, D., & Mu¨ller, C., (2015). Plant growth improvement mediated by nitrate capture in co-composted biochar. *Science Republica*, 5: 11080.

Karlidag, H., Esitken, A. Yildirim, E. Donmez, M.F. & Turan, M. (2011). Effects of plant growth promoting bacteria (PGPB) on yield, growth, leaf water content, membrane permeability and ionic composition of strawberry under saline conditions. *Journal of Plant Nutrition*, 34:34–45.

Kasim, W.A., Osman, M.E., Omar, M.N., Abd El-Daim, I.A., Bejai, S., & Meijer, J,. (2013). Control of drought stress in wheat using plant growth promoting bacteria *Journal Plant Growth Regulator*, 32: 122-130.

Katungi, E. Smale, M. Machethe, C. & Tushemereirwe, W.K. (2007). Social capital and soil fertility management in banana production systems of Uganda, University of Pretoria.

Kaur, G., & Reddy, M.S. (2014). Influence of P-solubilizing bacteria on crop yield and soil fertility at multilocational sites. *European Journal Soil Biology*, 61:35-40.

Kayat, F., Mohammad, A., Idris A.A., Ibrahim, M.F, Soon J.M., Ahmad Yusuf M.K., Wong K.F. & Zulariff A.L. (2016). Proceeding from Second Asia Pacific Conference on Advanced Research (APCAR): Study of the intention of

banana growers in improving the production in Jeli, Kelantan, APCAR, Melbourne, February, 2016.

Killan, M., Steiner, U., Krebs, B., Junge, H., Schmiedeknecht, G., & Hain, R. (2000). FZB24® *Bacillus subtilis* – mode of action of a microbial agent enhancing plant vitality, *Pflanzenschutz-Nachrichten Bayer*, 1: 72-93.

Kloepper, J.W. & Metting, Jr. FB. (1992). Plant growth-promoting rhizobacteria as biological control agents.: applications in agricultural and environmental management. *Soil microbial ecology*, 255-274.

Kloepper, J.W., Ryu, C.M., & Zhang, S.A. (2004). Induced systemic resistance and promotion of plant growth by *Bacillus spp*. *Phytopathology*, 94:1259-1266.

Kouki, S., N. Saidi, B.A. Rajeb, M. Brahmi, A. Bellila, M. Fumio, A. Hefi . ene, N. Jedidi, J. Downer, & H. Ouzari. (2012). Control of Fusarium wilt of tomato caused by. *fusarium oxysporum* F. sp. radicis-lycopersici using. mixture of vegetable and posidonia oceanica compost. *Applied and Environmental Soil Science*, 1–11.

Krasensky, J., & Jonak, C. (2012). Drought, salt, and temperature stress-induced metabolic rearrangements and regulatory networks. *Journal Experimental Botany*, 63(4):1593-608.

Kulkarni, V.M, Suprasanna, P., & Bapat, V.A. (2006). Plant regeneration through multiple shoot formation and somatic embryogenesis in a commercially important and endangered Indian banana cv. Rajeli. *Current Science*. 90: 842-846.

Lacerda, C.F., Cambraia, J., Oliva, M.A., & Ruiz, H.A. (2001). Plant growth and solute accumulation and distribution in two sorghum genotypes, under NaCl stress. *Revista Brasileira de Fisiologia Vegetal*, 13:270-284.

Lehmann, J., da Silva Jr J.P., Steiner, C., Nehls, T. Zech, W. & Glaser. B. (2003). Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central Amazon Basin: fertilizer, manure and charcoal Amendments. *Journal of Plant and Soil*. 249(2): 343-357.

Lehmann, J., Gaunt, J., & Rondon, M. (2006). Biochar sequestration in terrestrial ecosystems: a review. *Mitig Adapt Strategy Global Change*, 11: 403–27.

Lehmann, J., Rillig, M.C., & Thies, J. (2011) Biochar effects on soil biota – a review. *Soil Biology and Biochemistry*, 43, 1812–1836.

Leite, H.A., Silva, A.B., Gomes, F.P., Gramacho, K.P., Faria, J.C., de Souza, J.T. & Loguercio, L.L. (2013). *Bacillus subtilis* and Enterobacter cloacae endophytes from healthy *Theobroma cacao* L. trees can systemically colonize seedlings and promote growth. *Applied Microbiol Biotechnology*, 97: 2639–265.

Lepoivre, P. (2003). Phytopathogie: bases moleculaires de biologiques des pathsystemes et fondement des strategies de lutte. De Boeck & Presses Agronomiques de Gembloux (Eds.), Brussels, Belgium, pp. 149-167.

Liang, B., Lehmann, J., & Solomon, D., (2006). Black carbon increases cation exchange capacity in soils. *Soil Science Society of American Journal*, 70: 1719–30.

Lim, J. H., & Kim, S.D. (2013). Induction of drought stress resistance by multi-functional PGPR *Bacillus licheniformis* K11 in pepper. *Plant Pathology Journal*, 29: 201–208.

Linford M.B. (1928). A Fusarium wilt of peas in Wisconsin. Wisconsin. *Agriculture Experimental State Research Bulletin*. 85.

Liu, F., Xing, S., & Ma, H. (2013). Cytokinin-producing, plant growth-promoting rhizobacteria that confer resistance to drought stress in Platycladus orientalis container seedlings. *Applied Microbiol Biotechnology*, (2013) 97: 9155.

Lutts, S., Kinet, J., & Bouharmont, J. (1996). Effects of salt stress on growth, mineral nutrition and proline accumulation in relation to osmotic adjustment in rice (*Oryza sativa* L.) cultivars differing in salinity resistance. *Plant Growth Regulation*, 19:207-218.

Malviya, M.K., Sharma, A., Pandey, A., Rinu, K, Sati, P. & Palni, L.M.S. (2012). *Bacillus subtilis* NRRL B-30408: A potential inoculant for crops grown under rainfed conditions in the mountains, *Journal of Soil Science and Plant Nutrition*, 12 (4):811-824.

Martinsen, V., Alling, V., Nurida, N.L., Mulder, J., Hale, S.E., Ritz, C., Rutherford, D.W., Heikens, A., Breedveld, G.D., & Cornelissen, G. (2015) pH effects of the addition of three biochars to acidic Indonesian mineral soils. *Soil Science and Plant Nutrition*, 61:5, 821-834.

Marulanda, A., Jose´-Miguel, B., & Azcon, R. (2009). Stimulation of plant growth and drought tolerance by native microorganisms (AM fungi and bacteria) from dry environments: mechanisms related to bacterial effectiveness. *Journal of Plant Growth Regulator*, .28:115-124.

Maryani, N., Lombard, L., Poerba, Y. S., Subandiyah, S., Crous, P. W., & Kema, G. H. J. (2018). Phylogeny and genetic diversity of the banana Fusarium wilt pathogen Fusarium oxysporum f. sp. cubense in the Indonesian centre of origin. Studies in mycology, 92, 155-194.

McLean, E.O. (1982). Soil pH and lime requirement. In Page, A. L., R. H. Miller and D. R. Keeney (eds.) Methods of soil analysis. Part 2 - Chemical and microbiological properties. (2nd Ed.). *Agronomy* 9:199-223.

McMilan, S., (2007). Promoting Growth with PGPR. The Canadian Organic Grower. Retrieved from www.cog.ca.

Meloni, D.A., Oliva, M.A., Martinez, C.A., Cambraia, J., (2003). Photosynthesis and activity of superoxide dismutase, peroxidase and glutathione reductase in cotton under salt stress. *Environmental Experimental Botany*, 49:69–76.

Mia, M. B., Shamsuddin, Z. H., Wahab, Z., & Marziah, M. (2010). Rhizobacteria as bioenhancer and biofertilizer for growth and yield of banana (*Musa spp*. cv.'Berangan'). *Scientia horticulturae*, 126(2), 80-87.

Mika, F., Ziv, A., & David, W. (2016). Cytokinin activity increases stomatal density and transpiration rate in tomato. *Journal of Experimental Botany*, 67(22): 6351–6362.

Mohamad Roff, M.N, Tengku Abdul Malik, T.M, Sharif, H. (2012). Challenges to banana production in Malaysia: A threat to food security. *The planter,* 88(1030): 13-21.

Munné-Bosch S, Penueles L. (2003). Changes in carotenoids, tocopherols and diterpenes during drought and recovery, and the biological significance of chlorophyll loss in *Rosmarinus officinalis* plants. *Planta*. 210:925–931.

Myresiotis, C.K., Vryzas, Z., Papadopoulou-Mourkidou, E. (2014) Enhanced root uptake of acibenzolar-S-methyl (ASM) by tomato plants inoculated with selected Bacillus plant growth-promoting rhizobacteria (PGPR). *Applied Soil Ecology*.77:26-33.

Nadeem, S.M., Imran, M., Naveed, M., Khan, M.Y., Ahmad, M., Zahir, Z.A., & Crowley, D.E. (2017). Synergistic use of biochar, compost and plant growth-promoting rhizobacteria for enhancing cucumber growth under water deficit conditions. *Journal of the Science of Food and Agriculture*. 97(15):5139-5145.

Nelson, S.C., Ploetz R.C. & Kepler. A.K. (2006). *Musa* species (bananas and plantains), ver. 2.2. In: C.R. Elevitch (Ed.), Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i

Noctor, G., Veliovic-Jovanovic, S., & Foyer, C.H. (2000). Peroxide processing in photosynthesis: antioxidant coupling and redox signaling. *Philosophical transaction of the royal society*, 355: 1465-1475.

Nonami, H. (1998) Plant water relations and control of cell elongation at low water potentials. *Journal of Plant Research*. 111, 373–382.

Ommen, O.E., Donnelly, A., Vanhoutvin, S., van Oijen M. & Manderscheid, R. (1999). Chlorophyll content of spring wheat flag leaves grown under elevated CO_2 concentrations and other environmental stresses within the ESPACE wheat project. *European Journal of Agronomy*. 10: 197-203.

Ortiz, R. & Vuylsteke, D. (1996). Recent advances in Musa genetics, breeding and biotechnology. *Plant Breeding*, 66: 1355-1363.

Ozgur, T. & Mithat, N.G, (2008). Influence of Water Stress on Proline Accumulation, Lipid Peroxidation and Water Content of Wheat. *Asian Journal of Plant Sciences*, 7: 409-412.

Pace, M.L., Cole, J.J., Carpenter, S.R., & Kitchell. J.F. (1999). Trophic cascades revealed in diverse ecosystems. *Trends in Ecology and Evolution* 14:483–488.

Parkinson, D., Gray, T.R.G. & Williams, S.T. (1971). Methods for studying the ecology of soil microorganisms. IBP Handbook No. 19. Blackwell Scientific Publications, Oxford.

Pellizzari, E.D, Kuj J., & William, E.B. (1976). A hypersensitive reaction in Mallus species: changes in the leakage of electrolytes from apple leaves after inoculation with *Venturia inaequalis*. *Phytophatology*, 66: 373-376.

Perez, L., Dita, MA, & Martinez, E. (2014). Prevention and diagnostic of Fusarium Wilt (Panama disease) of banana caused by *Fusarium oxysporum f. sp. cubense* Tropical Race 4 (TR4), *Food and Agriculture Organization of the United Nations*.

Ploetz, R.C. (2006) Panama disease: An old nemesis rears its ugly head. Part2. The Cavendish era and beyond. Plant Health Progress. St. Paul USA: Plant Management Network.

Ploetz, R. C. (2015). Fusarium wilt of banana. Phytopathology, 105(12): 1512-1521.

Poltez, R.C. Kelper, A.K., Daniells, J., & Nelson, C. (2007). Banana and plantain-an overview on pacific island cultivars, Species profiles for pacific island agroforestry, www.traditionaltree.org.

Pompelli, M.F., Barata-Luis, R., Vitorino, H., Gonclaves, E., Rolim, E., Santos, M., Almeida-Cortez, J., & Endrez, L. (2010). Photosynthesis, photoprotection and antioxidant activity of purging nut underdrought deficit and recovery. *Biomass Bioenergy*, 34:1207-1215.

Quan, R., Shang, M. Zhang, H. Zhao, Y. & Zhang, J. (2004). Engineering of enhanced glycine betaine synthesis improves drought tolerance in maize. *Plant Biotechnology Journal*, 2(6): ,-486.

Rabileh, M.A., Shamshuddin, J., Panhwar, Q.A., Rosenani, A.B. & Anuar, A.R. 2015. Effects of biochar and/or dolomitic limestone application on the properties of Ultisol cropped to maize under glasshouse conditions. *Canadian Journal of Soil Science*. 95: 37-47.

Reis, V.M, Baldani, V.L.D, & Baldani, J.I. (2015). Isolation, identification and biochemical characterization of *Azospirillum spp*. and other nitrogen-fixing bacteria. In Handbook for Azospirillum. Switzerland: *Springer International Publishing*, 3-26.

Richards, L.A. (1947). Pressure-membrane apparatus, construction and use. *Agriculture Engineering*, 28: 451-454.

Robinson, J.C., & Nel, D.J. 1985. Comparative morphology, phenology and production potential of banana cultivars 'Dwarf Cavendish' and 'Williams' in the Eastern Transvaal lowveld *Scientia Horticulture*., 25 (1985): 149-161.

Sairam, R.K., Srivastava, G.C., Agarwal, S., & Meena, R.C. (2005): Differences in antioxidant activity in response to salinity stress in tolerant and susceptible wheat genotypes. *Biologia Plantarum,* 49: 85–91.

Sampath, K.P., Debjit Bhowmik, D.S., & Umadevi, M. (2012). Traditional and medicinal uses of banana. *Journal Pharmacognosy Phytochemical*., 1:3.

Saravanan,, T., Muthusamy, M. & Marimuthu, T. (2003). Development of integrated approach to manage the fusarial wilt of banana. *Crop Protection*, 22: 1117–1123.

Schisler, D.A., Khan, N.I., & Boehm, M.J. (2002). Biological control of Fusarium head blight of wheat and deoxynivalenol levels in grain via use of microbial antagonists. Mycotoxins and Food Safety: *Springer*. 53–69.

Schoeneweis, D.F. (1978). Water stress as a predisposing factor in plant disease**. *In***: "Water Deficit and Plant Growth. T.T. Kozlowski, (***ed***.). Volume 5. Academic Press, New York.

Shamshuddin, J. & Fauziah, C.I. (2010). Weathered tropical soils: The Ultisol and Oxisol. UPM Press, Serdang, Malaysia.

Sharma, A.K. (2003). Biofertilizers for sustainable agriculture.Dr. Updesh Purohit for Agribios, Jodhpur, India.

Shi, Y., Lou, K. & Li, C. (2010). Growth and photosynthetic efficiency promotion of sugar beet (*Beta vulgaris* L.) by endophytic bacteria. *Photosynthesis Research,* 105:5-13.

Singh, H.P., Uma, S., Selvarajan, R., & Karihaloo J.L. (2011). Micropropagation for Production of Quality Banana Planting Material in Asia-Pacific. Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB), New Delhi, India. P. 92.

Smirnoff, N. (1995). Antioxidant systems and plant response to the environment. In: Smirnoff V (Ed.), Environment and Plant Metabolism: Flexibility and Acclimation, BIOS Scientific Publishers, Oxford, UK.

Solomon, D., Lehmann, J., Kinyangi, J., Amelung, W., Lobe, I., Pell, A., Riha, S., Ngoze, S., Verchot, L., Mbugua, D., Skjemstad, J., & Schafer, T. (2007). Long-term impacts of 31 anthropogenic perturbations on dynamics and

speciation of organic carbon in tropical forest and subtropical grassland ecosystems. *Global Change Biology*, 13: 511-530.

Specht, J.E., Chase, K., Macrander, M., Graef, G.L, Chung, J., Markwell, J.P., Germann, M. Orf, J.H. & Lark, K.G. (2001). Soybean response to water. A QTL analysis of drought tolerance. *Crop Science*, 41: 493–509.

Srivalli B., Sharma G., & Khanna-Chopra R. (2003): Antioxidative defense system in an upland rice cultivar subjected to increasing intensity of water stress followed by recovery. *Physiologia Plantarum*, 119: 503–512.

Stein, T. (2005). *Bacillus subtilis* antibiotics: structures, synthesis and specifics functionns. *Molecular Microbiology*. 56: 845-847.

Teh, C.B.S., & Jamal, T. (2006). Water Retention. In: Soil Physic Analyses. University Putra Malaysia Press, Selangor, Malaysia, 14-17.

The Biology of *Musa* L. (banana). (2008). Department of Health and Ageing Office of the Gene Technology Regulator: Australia.

Theeba, M., Ilani, Z.I. & Nor Faddilah, A.H. (2016). Biorichar: Biochar-Based Organic Fertilizer. Soil Science Research Center, MARDI.

Timmusk, S., Abd El-Daim, IA., Copolovici, L., Tanilas, T., Känn aste, & A., Behers, L. (2014). Drought tolerance of wheat improved by rhizosphere bacteria from harsh environments: enhanced biomass production and reduced emissions of stress volatiles. 9(5).

Touré, Y., Ongena, M., Jacque,s P., Guir,o A., & Thonart, P. (2004). Role of lipopeptides produced by Bacillus subtilis GA1 in the reduction of grey mould disease caused by Botrytis cinerea on apple. *Journal of Applied Microbiology*. 96: 1151-1160.

Trupiano, D., Cocozza, C., Baronti, S., Amendola, C., Primo, F., Vaccari, F.M., Lustrato, G., Di Lonardo, S., Fantasma, F., Tognetti, R., & Scippa, G.S. (2017). The effects of biochar and its combination with compost on lettuce (*Lactuca sativa* l.) growth, soil properties, and soil microbial activity and abundance. *International Journal of Agronomy*, 12.

Turan, M., Ekinci, M., Yildirim, E. , Güneş A. , Karagöz, K., Kotan R., & Dursun A. (2014). Plant growth-promoting rhizobacteria improved growth, nutrient, and hormone content of cabbage (*Brassica oleracea*) seedlings, *Turkish Journal of Agriculture Forestry*, 38: 327-333.

Turner, D.W. & Thomas, D.S. (1998). Measurements of plant and soil water status and their association with leaf gas exchange in banana (*Musa spp*.): a laticiferous plant. *Scientia Horticulturae,* 77:177-193.

Turner, D.W., Fortescue, J.A. & Thomas, D.S. (2007). Environmental physiology of the bananas (*Musa spp*.). *Brazilian Journal of Plant Physiology*, 19:463–484.

Turner, D.W, & Lahav, E. (1983). The growth of banana plants in relation to temperature. *Australian Journal of Plant Physiology*, 10:43-54.

Upadhyay, SK., J.S. Singh, A.K. Saxena & D.P. Singh. (2012). Impact of PGPR inoculation on growth and antioxidant status of wheat under saline conditions. *Plant Biology*., 14: 605-611.

Vardharajula, S., Zulfikar, Ali S., Grover, M., Reddy, G., & Bandi ,V. (2011).Drought-tolerant plant growth promoting *Bacillus spp.*, effect on growth, osmolytes, and antioxidant status of maize under drought stress. *Journal Plant International*, 6:1–1

Vendruscolo, A.C.G, Schuster, I., Pileggi, M., Scapim, C.A., Molinari, H.B.C., Marur, C.J., & Vieira, L.G.C. (2007). Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. *Journal Plant Physiology*. 164(10): 1367-1376.

Vivas, A., Marulanda, A., Ruiz-Lozano, J.M, Barea, J.M, & Azcon, R. (2003). Influence of *Bacillus spp*. on physiological activities of two arbuscular mycorrhizal fungi and on plant response on PEG- induced drought stress. *Mycorrhiza*, 13:249-256.

Vurukonda, SSKP., Vardharajula, S., Shrivastava, M., & Ali SKZ.(2016). Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria. *Microbiological Research*, 184:13-24.

Wang, C.J., Yang, W., Wang, C., Gu, C., Niu, D.D., Liu, HX., Wang, Y.P., & Guo, JH. (2012) Induction of drought tolerance in cucumber plants by a consortium of three plant growth-promoting rhizobacterium strains,.*PLoS ONE* 7(12).

Wang, Z., & Stutte, G.W. (1992). The role of carbohydrates in active osmotic adjustment in apple under water stress. *Journal American Society Horticulture Science*, 117: 816-823.

Waqas, M, Shahzad, R, Hamayun, M, Asaf, S, Khan, AL, Kang, S.M, Yun, S., Kim, K.M., Lee, I.J. (2018) Biochar amendment changes jasmonic acid levels in two rice varieties and alters their resistance to herbivory. *PLOS ONE* 13(1).

Weatherly, P.E. (1950). Studies in the water relations of cotton. 1. The field measurement of water deficits in leaves. *New Phytol*. 49:81-97.

Weinert, M. & Simpson, M. (2016). Sub-tropical banana nutrition: matching nutrition requirements to growth demands.Queensland government.

Whipps, J.M. (2001). Microbial interactions and biocontrol in the rhizosphere. *Journal Experimental Botany*, 52:487–511.

William, K., & Qureshi, R.A. 2015. Evaluation of biochar as fertilizer for the growth of some seasonal vegetables. *Journal of Bioresource Management,* 2(1).

Wigglesworth,(2007). Uses of abaca, retrieved from http://www.Wigglesworthfibres.com/Products/Abaca/Usesofabaca.html

Woldetsadik D., Drechsel P., Keraita B., Marschner B., Itanna F., & Gebrekidan H. (2016): Effects of biochar and alkaline amendments on cadmium immobilization, selected nutrient and cadmium concentrations of lettuce (*Lactuca sativa*) in two contrasting soils. *Springer Plus*, 5: 397.

Woyessa, D. & Assefa, F. (2011). Effects of Plant Growth Promoting Rhizobaceria on Growth and Yield of Tef (*Eragrostis tef Zucc. Trotter*) under Greenhouse Condition. *Research Journal of Microbiology*, 6: 343-355.

Wu, Q.S., Xia, R.X. & Zou, Y.N. (2008). Improved soil structure and citrus growth after inoculation with three arbuscular mycorrhizal fungi under drought stress. *European Journal Soil Biology*., 44: 122–128.

Xiang Y., Deng, Q., Duan, H., & Guo, Y. (2017). Effects of biochar application on root traits: a meta-analysis, *GCB Bioenergy*, 9, 1563–1572.

Xie, X., Zhang, H., & Pare, P. (2009). Sustained growth promotion in arabidopsis with long-term exposure to the beneficial soil bacterium *Bacillus subtilis* (GB03*). Plant Signal Behaviour*, 4: 948–953.

Yadeta, K.A., & Thomma, B.P. (2013). The xylem as battleground for plant hosts and vascular wilt pathogens. *Frontier Plant Science*, 4: 97.

Yang, Lu, Shuang, R., Fei, H., Yixia, C., Guoping, W., & Kunzheng, C. (2016). Effects of biochar amendment on tomato bacterial wilt resistance and soil microbial amount and activity. *International Journal of Agronomy*, accepted journal.

Ye, S.F., Zhou, Y.H., Sun, Y., Zou, L.Y, & Yu, J.Q. (2006). Cinnamic acid causes oxidative stress incucumber roots, and promotes incidence of Fusarium wilt. *Environmental Experimental Botany*, 56:255–26.

Yu, G.Y., Sinclair, J.B., Hartman, G.L., & Bertagnolli, B.L. (2002) Production of iturin A by *Bacillus amyloliquefaciens* suppressing *Rhizoctonia solani*. *Soil Biology Biochemistry*, 34:955–963.

Yuan, J.H., Xu, R.K., Qian, W., & Wang, R.H. (2011). Comparison of the ameliorating effects on an acidic ultisol between four crop straws and their biochars. *Journal Soils and Sediments*, 11(5): 741–750.

Yusnita & Sudarsono. (2004). Metode inokulasi dan reaksi ketahanan 30 genotipe kacang tanah terhadap penyakit busuk batang Sclerotium. *Hayati*, 11:53-58.

Zemanová, V., Břendová, K., Pavlíková, D., Kubátová, P., & Tlustoš, P. (2017): Effect of biochar application on the content of nutrients (Ca, Fe, K, Mg, Na, P) and amino acids in subsequently growing spinach and mustard. *Plant Soil Environment*, 63: 322–327.

Zhang, H., Xie, X., Kim, M.S., Kornyeyev, D.A., Holaday, S., & Paré, P.W. (2008). Soil bacteria augment Arabidopsis photosynthesis by decreasing glucose sensing and abscisic acid levels in planta. *Plant Journal*, 56: 264–273.

Zhang, H., Mallik, A., & Zeng, R. S. (2013). Control of Panama disease of banana by rotating and intercropping with Chinese chive (*Allium tuberosum* Rottler): role of plant volatiles. *Journal of chemical ecology*. 39(2): 243-252.

Zhang, J., Jia, W. Yang, J.,& Ismail, A.M. (2006). Role of ABA in integrating plant response to drought and salt stresses. *Field Crops Research*, 97: 111-119.

Zlatev, Z., & Stotanov, Z. (2005). Effect of water stress on leaf water relations of young bean plants. *Journal Central Europe Agriculture*, 6(1): 5-14.

Zornoza, R., Mataix-Solera, J., Guerrero, C., Arcenegui, V., Mayoral, A.M., Morales, J., & Mataix-Benyto, J. (2007). Soil properties under natural forest in the Alicante Province of Spain. *Geoderma*, 142(3): 334-341.

BIODATA OF STUDENT

Siti Norliza Binti Mohd Din was born in 10 February 1993 in Pasir Puteh, Kelantan. She began her primary school in Sekolah Kebangsaan Gong Garu in 2000. Later, she extended her secondary education in Sekolah Menengah Kebangsaan Jeram in 2006 and completed her SPM in 2010. She furthered her study in Foundation of Agriculture Science for one year at Universiti Putra Malaysia and continued with her Bachelor Degree in Agriculture Science. She obtained her Bachelor Degree in 2016 and straightforward enrolled to her Master Degree study majors in Horticulture Science at Department of Crop Science, Faculty of Agriculture, UPM. During her study period, she has participated as poster presenter in Malaysian Society of Plant Physiology Conference (21-23 August 2017) and 6th International Agriculture Student Symposium (4-13 February 2018). She also particaped as a member in a community programme of "Empowering human talent of the prison's community through lifelong learning in banana herbs industrial cultivation opportunity", a programme under UCTC. She was ambitious to be a lecturer and a generous businesswoman. The author love nature and agriculture. She was hoping that agriculture in Malaysia could be an outstanding field in the world occupied with a new technology and innovation.

LIST OF PUBLICATION

Norliza, **M.S.,** S.S. Zaharah, K. Sijam, M.Z. Aiman Takrim, B. Ali, T. Manickam & J. Tan. (2018). Effect of Biorichar amendment on growth, nutritional properties and biochemical changes of banana (*Musa acuminata*) cv. berangan established in an ultisol soil at vegetative stage. *Journal of Tropical Plant Physiology*, accepted manuscript.

Norliza, **M.S.,** S.S. Zaharah, K. Sijam, M.F Ramlan, M.Z. Aiman Takrim, B. Ali. (2018). Potential of *Bacillus subtilis* inoculated on Biorichar amended soil for suppression of fusarium wilt, biochemical changes and leaf gas exchange under water stress condition of banana (*Musa acuminata*) cv. Berangan. *Fundamental of Applied Agriculture*, accepted manuscript.

Norliza, **M.S.,** S.S. Zaharah, K. Sijam, M.F Ramlan, M.Z. Aiman Takrim, B. Ali. (2018). Physiological change of banana by inoculation of *Bacillus subtilis* under water stress challenged with fusarium.*Plant, Soil and Environment Journal*, submitted manuscript.

Aiman Takrim, M.Z., S.S. Zaharah, M.F. Ramlan, H.ZE Jaafar, B. Ali and **M.S. Norliza**. (2018). Morphological and physiological changes of banana (*Musa acuminata* cv. Berangan) to brassinolide at nursery stage. *Journal of Tropical Plant Physiology*, accepted manuscript.

Aiman Takrim, M.Z., S.S. Zaharah, M.F. Ramlan, H.ZE Jaafar, B. Ali and **M.S. Norliza**. (2018). Influence of Water Stress in Association with Aplication of Brassinolide and Minerals on Growth, Physiological and Biochemical Changes of Banana (*Musa acuminata* cv. Berangan). *Journal of Agrobiotechnology*, submitted manuscript.

Aiman Takrim, M.Z., S.S. Zaharah, M.F. Ramlan, H.ZE Jaafar, J. A. Shukor, B. Ali and **M.S. Norliza**. (2018). Effect of different water regime and plant growth regulators on growth, physiology and yield of banana (*Musa acuminata* cv. berangan) in tropical. *Fundamental of Applied Agriculture*, submitted manuscript.

Hawa, Z.E.J., Siti Zaharah, S., Puteri Edaroyati, M.W., Kamaruzaman, S., Md Aiman Takrim Z., Alias, A.A, **Siti Norliza M.D**., Rudy, T., Muhammad Adip, M.T., (2017). Proceeding from NCKT '17: Empowering human talent of the prisons' community through lifelong learning in banana herbs industrial cultivation opportunity. 4th International Conference on Knowledge Transfer, 11-12 December 2017, Kedah.

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